Chapter 2
Locating Fracture Critical Members

2-1. Fracture Critical Members

a. The AASHTO (1996) Guide Specification for Fracture Critical Bridge Members states that "Fracture Critical Members or member components are tension members or tension components of members whose failure would be expected to result in collapse of the bridge." To qualify as a FCM, the member must be a nonredundant member subject to tensile force. There must not be any other member or system of members which will serve the functions of the member in question should it fail. This has also been interpreted to include bending members which experience tensile forces over part of their cross section, whose failure would be expected to result in collapse of the bridge. Compression members or components are not considered fracture critical. Since it is considered undesirable from an operation and maintenance standpoint to have a bridge member yield, collapse is taken to mean yielding has occurred. This is consistent with the approach used by the Federal Highway Administration. The FCM can be identified by removing the member in tension and checking the remaining members in the bridge to see if any members have yielded. Information on redundancy in bridge framing systems and of tension members, along with the necessary definitions, are included in Chapter 2 of the Federal Highway Administration's "Bridge Inspector's Training Manual 90" (Hartle et al. 1991). In addition, pertinent articles on FCMs have been published in Civil Engineering (1987).

b. To locate the FCMs in a bridge, both dead and live loads must be considered in the structural analysis. As defined by AASHTO Standard Specifications for Highway Bridges (1996), dead loads are the weight of the complete structure, including the roadway, sidewalks, car tracks, pipes, conduits, cable, and other public utility services. Dead loads do not change with time and need to be considered as permanent loads acting on the structure. Live loads consist of the weight of applied moving loads such as vehicles and pedestrians. Live loading on the roadway of bridges or incidental structure shall consist of standard trucks or lane loads which are equivalent to truck trains. Two systems of loading, the H loading and the HS loading, are defined by AASHTO specifications (1996). Standard truck loads, wheel spacing, weight distributions, and clearances for standard H and HS truck loading can be obtained from the specification. H20-44 and HS20-44 standard truck loads that will be applied in the examples discussed later in this section are shown in Figure 2-1.

c. The lane loads consist of uniform load per linear foot of traffic lane combined with a single concentrated load (or two concentrated loads in the case of continuous spans) so placed on the span as to produce maximum stress. The

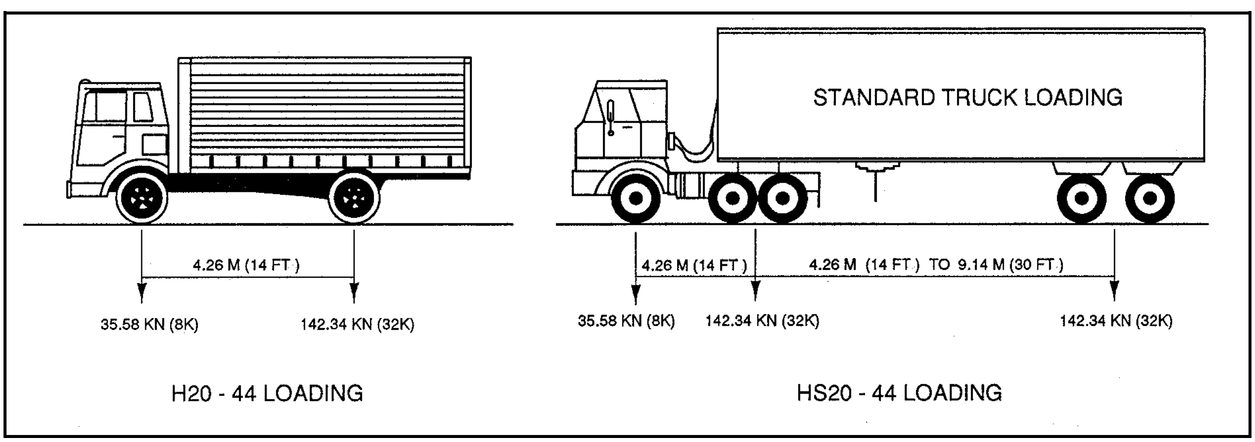

Figure 2-1. Standard truck loading

concentrated load and uniform load shall be considered as uniformly distributed over a 3-m (10-ft) width on a line normal to the center line of the lane. Figure 2-2 shows the lane loading for H20-44 and HS20-44. For the computation of moments and shears, different concentrated loads shall be used as indicated in Figure 2-2.

d. For continuous spans, the lane loading shown in Figure 2-2 needs to be modified by the addition of a second equal-weight concentrated load placed in one other span in the series in such position as to produce the maximum negative moment. Live load stresses produced by H or HS loading shall be increased for bridge superstructures and the portion of concrete or steel piles above the groundline which are rigidly connected to the superstructure as in rigid frames or continuous designs to account for impact effects. The amount of this allowance or increment should be calculated in accordance with AASHTO design specifications (1996).

2-2. Analysis Procedure for Locating FCMs of Non-Truss Bridges

a. Figure 2-3 shows flowcharts for locating FCMs in non-truss bridges. Dead loads and live loads must be applied to the bridge according to AASHTO requirements. A structural analysis is performed to determine the member forces. To locate FCMs, each tension member is removed on an individual basis to determine if its removal and the redistribution of forces cause any of the remaining members to yield. If yielding develops, the removed tension member is a FCM. The tested tension member is then reinstalled; the next tension member is removed, and the remaining members are again checked for yielding. This tension removal procedure continues until each tension member has been individually removed and the remaining members have been checked for yielding. After each tension member has been checked, a new live load condition is applied, and the tension member testing procedure is repeated. The FCMs for the entire bridge can be obtained utilizing this process.

b. Because this repeated analysis procedure can be very tedious and time consuming, the structural analysis can be performed by using a finite element structural program. ANSYS program (ANSYS 1992) is used for the example cases presented in paragraph 2-3.

2-3. Analysis Procedure for Locating FCMs of Truss Bridges

a. For truss bridges, the first step of the analysis is to decide the degree of indeterminacy. For a

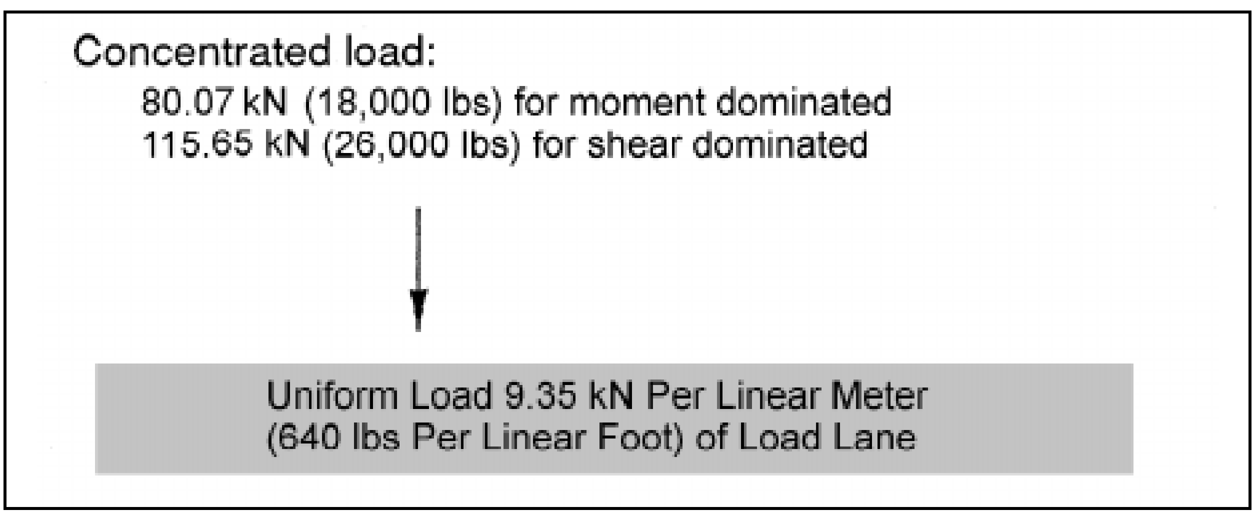

Figure 2-2. H20-44 lane loading and HS20-44 lane loading

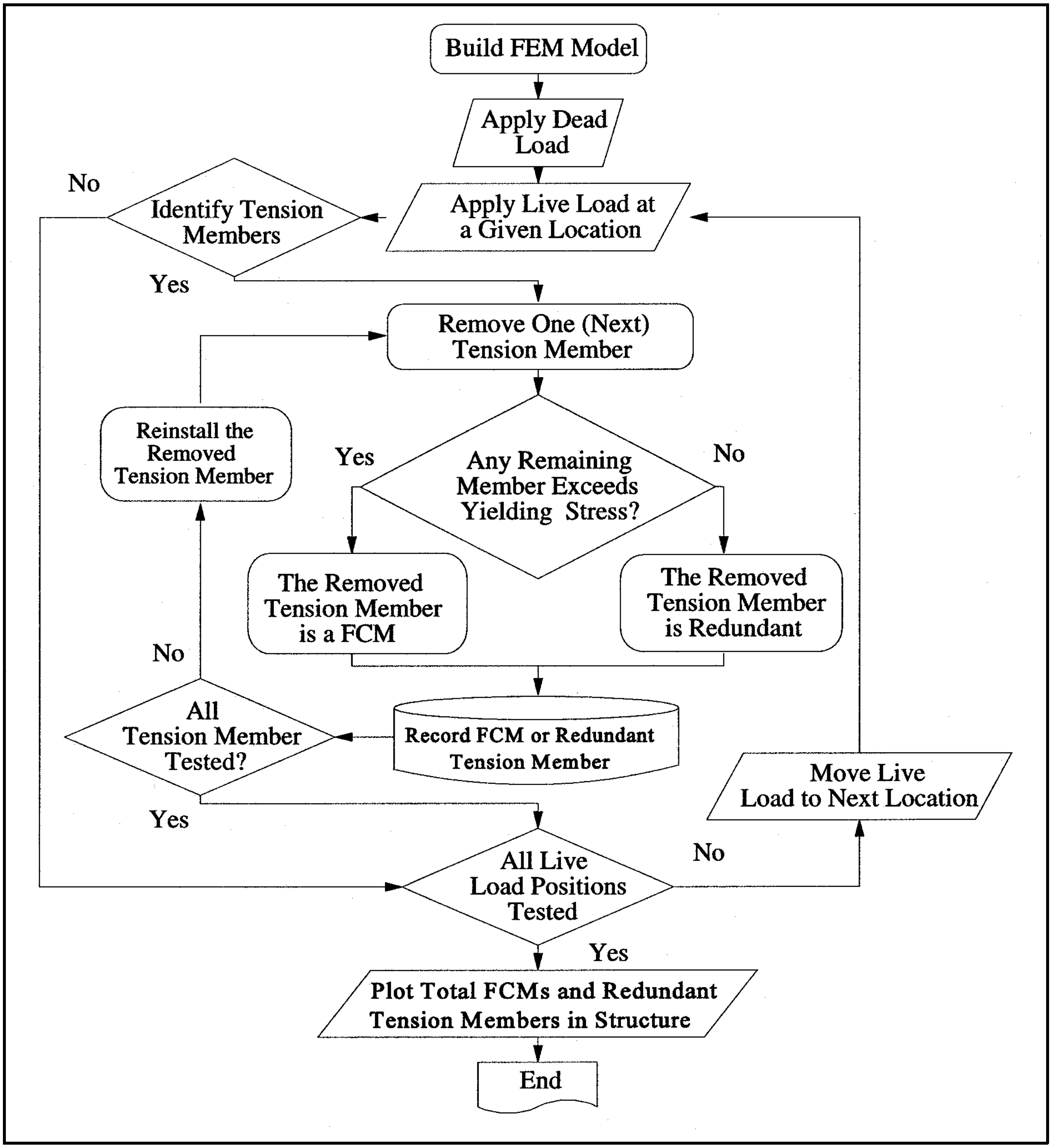

Figure 2-3. Flowchart for locating FCMs of non-truss bridges and indeterminate truss bridges using linear elastic and perfectly plastic model

determinate truss bridge all tension members are FCMs. The flowchart for determinating FCMs of determinate truss bridges is presented in Figure 2-4. For an indeterminate truss bridge, the procedure is similar to a non-truss bridge as plotted in the flowchart in Figure 2-3.

b. Example 1 is Summit Bridge, an inland waterway bridge (627.28 m (2,058 ft) total span) crossing the Delaware River and the Chesapeake Bay. The bridge approach is via several simple supported girders, followed by a 76.2-m (250-ft) single-span deck truss (Figure 2-5), and then onto

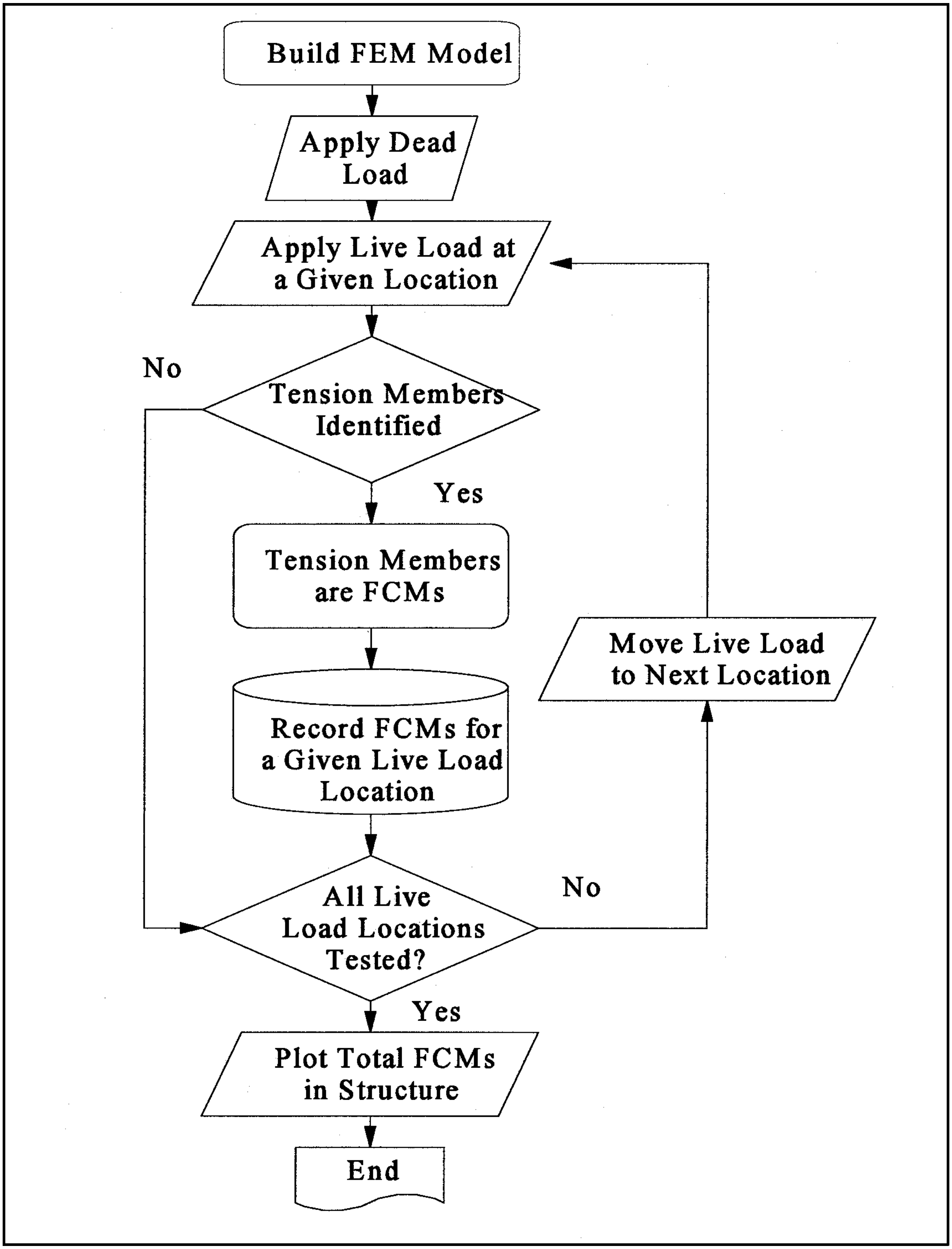

Figure 2-4. Flowchart for locating FCMs of statically determinate truss bridges

the 91.44-m (300-ft) anchor arm span and 182.88-m (600-ft) main span (Figure 2-6). The main span in the middle of the bridge (Figure 2-6) can be further divided into a suspended span and two cantilever spans. Figure 2-5 shows the finite element model of the deck truss. The deck truss system is a determinant (nonredundant) structure. Figure 2-6 shows the finite element model of the anchor arm and main spans. This bridge has four traffic lanes. The dead loads of each bridge member were applied according to the design data (USACE 1940). The design live load is a HS20-44 loading (Figure 2-2) plus an impact load of 111.2 kN (25 kips) (USACE 1940), except for the deck slab which is designed for 142.34 kN (32 kips) per axle load. The 9.35 kN per linear meter (640 lb per linear foot) of lane load was applied as a distributed load to the truss

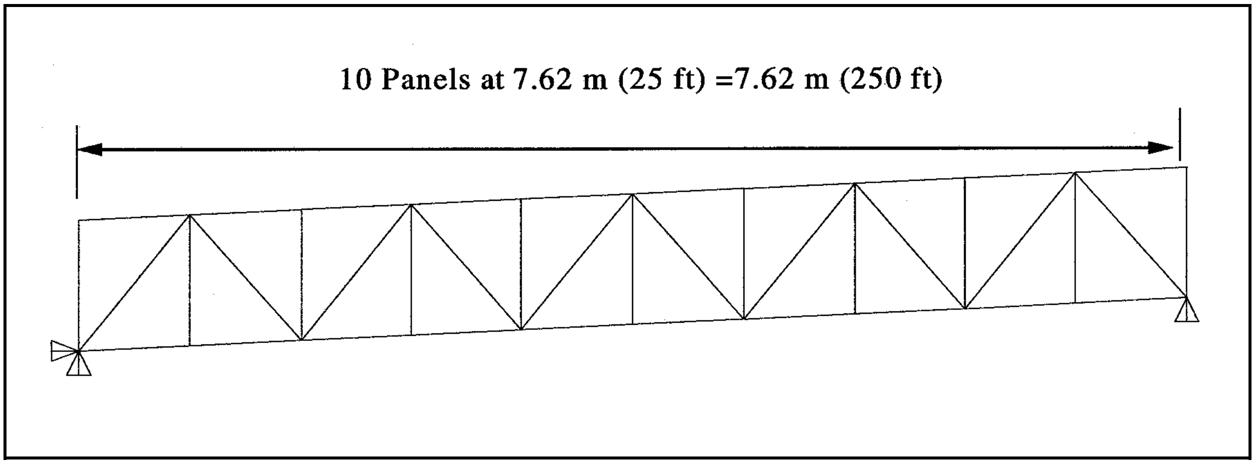

Figure 2-5. Summit Bridge (single-span deck truss)

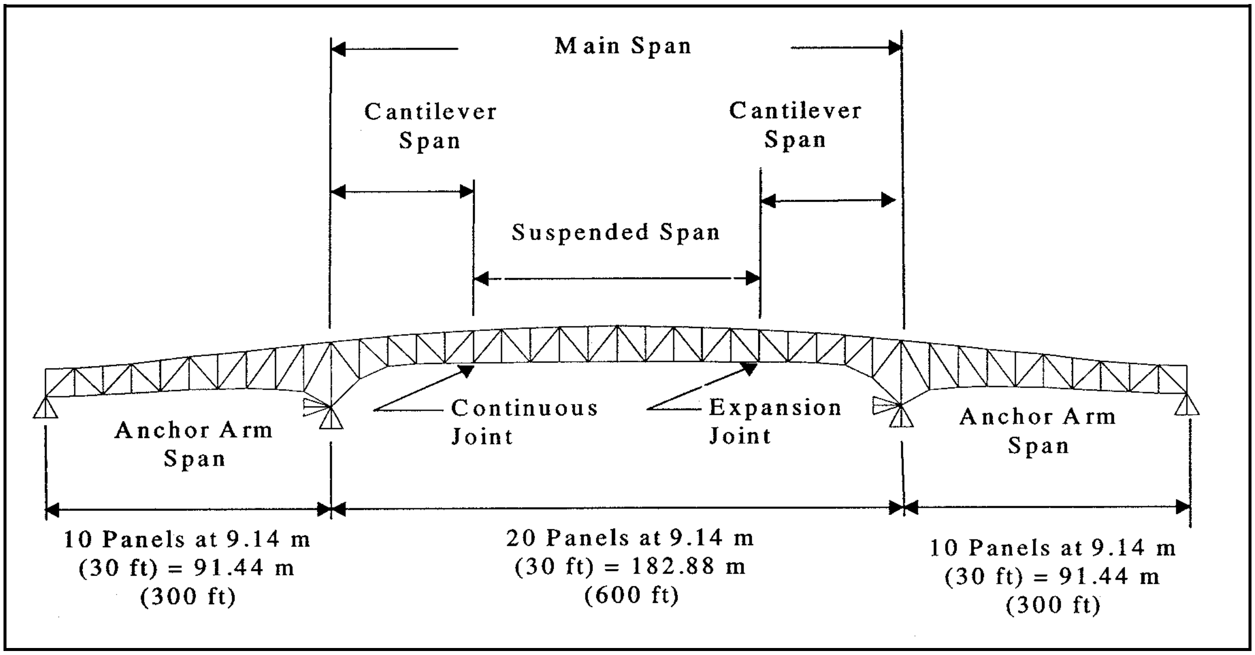

Figure 2-6. Summit Bridge (mid spans)

joints connected to the bridge deck. A concentrated live load of 115.65 kN (26 kips) plus the (111.2-kN (25-kip)) impact load were positioned at one truss joint connecting to the deck and were moved from one end of the bridge to the other end; then, the tension members were recorded. Since this is a determinate bridge, all the tension members recorded are FCMs. The results are shown in Figures 2-7 and 2-8.

c. Example 2 is St. George's Highway bridge, a tied-arch single span (164.59 m (540 ft)) bridge located in Delaware and Maryland crossing the Chesapeake and Delaware Canal. Since this bridge is not a truss bridge, Equation 2-1 does not apply. The finite element model is shown in Figure 2-9. St. George's Highway bridge is designed for H20-44 standard loading. As used for the Summit Bridge analysis, the same lane loading

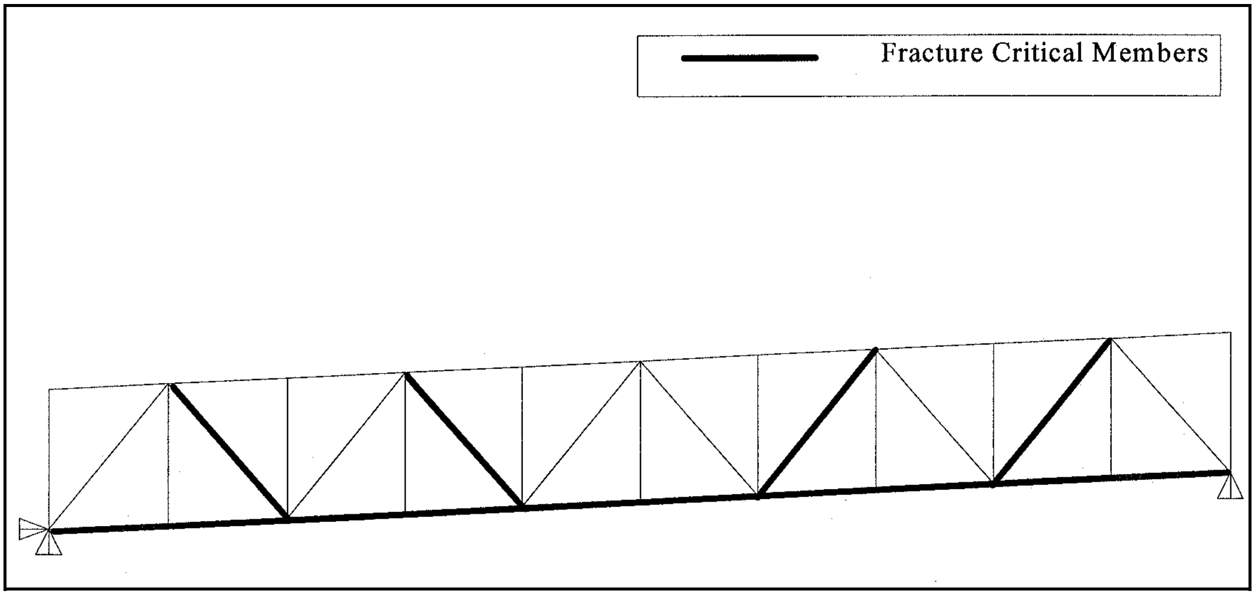

Figure 2-7. Summit Bridge (FCM in the simple span)

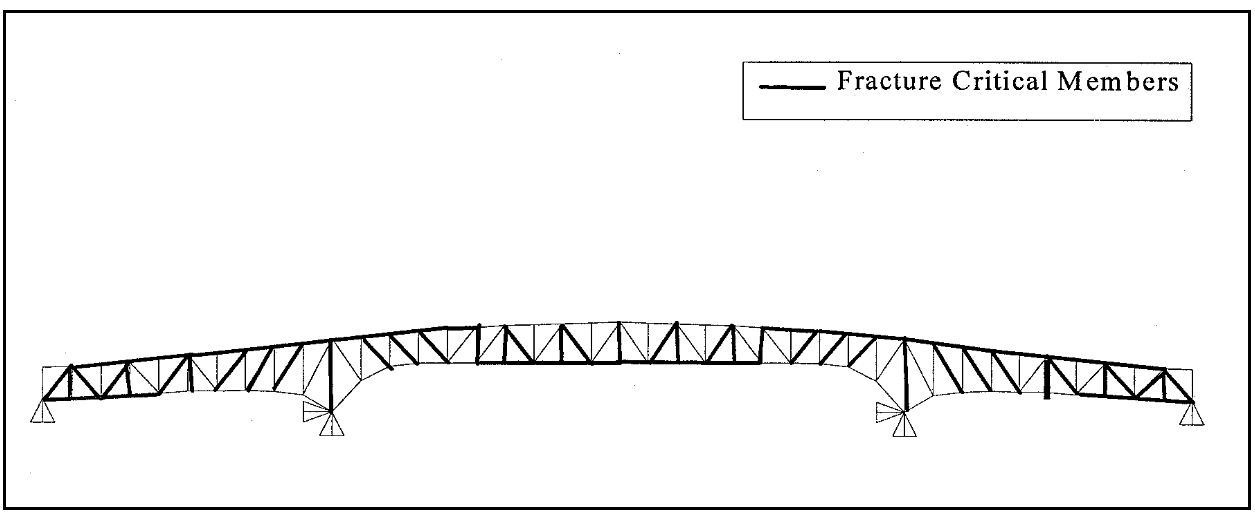

Figure 2-8. Summit Bridge (FCM in the mid spans)

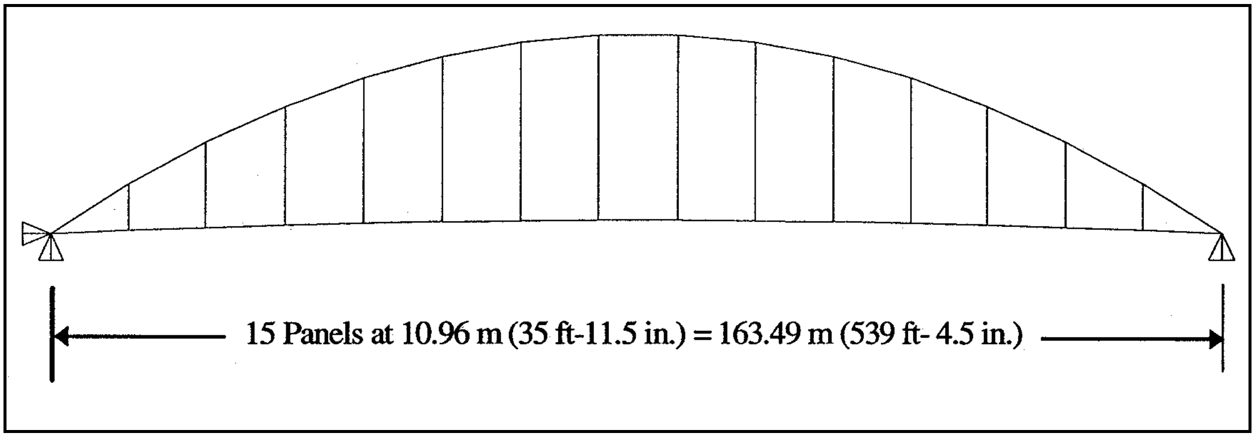

Figure 2-9. St. George's Highway Bridge (tied arch span)

(HS20-44) was applied to this bridge. After the dead loads were applied to each bridge member and the concentrated load was moved to all the deck joints, the tension members were identified (USACE 1956). For a concentrated loading position, each tension member was individually removed to determine if the redistribution of the load caused any remaining members to reach yield stress. If yielding occurred in the remaining members, the tension member removed was considered to be a FCM. If yielding did not occur, the removed tension member was considered a redundant member. The concentrated live load was then moved to the next deck joint. The process was repeated until all the FCMs were identified. The FCMs for the St. George's Highway Bridge are shown in Figure 2-10.

2-4. Guidance for Locating FCMs

a. From the results shown for the simple-span deck truss, it can be observed that the bottom chord must be composed of tension members because it stretches as the span bends. The diagonal truss members may be in tension or compression. Harland et al. (1986) proposed that, for controlling loads uniformly distributed across the span length, diagonals pointing upward towards the truss mid-span are subject to compression, while diagonals pointing upward away from the mid-span are subject to tension. The results from the Summit Bridge analysis shown in Figure 2-7 support Harland's proposition.

b. From the results shown in Figure 2-8, the top chord is in tension in the area over the piers. In the area near the end support (abutment), the truss is similar to the simple spans; therefore, the bottom chord is in tension. However, when using visual inspection of the framing arrangement, there are transient zones in which it is not obvious if the members are in tension or compression. The FCMs in these zones become obvious by analysis using the procedure outlined in Figure 2-3.

c. The suspended span for Summit Bridge acts as a simple span; therefore, the same principles as noted in paragraph 2-4*a* above apply as shown in Figure 2-8.

d. The tied-girder prevents the separation of supports; therefore, it is in tension. Any fracture in the girder will cause partial or total collapse of the bridge; therefore, the tied girder is a FCM. The members suspended from the arch are also subject to tension; however, they must be investigated to see if the failure of one suspension member could cause the remaining members to yield.

e. The guidelines set forth in this ETL can help bridge engineers to generally locate FCMs using visual observation. However, it is suggested that the procedures shown in Figures 2-3 and 2-4 be used to specifically identify the FCMs. FCMs should be identified during initial bridge design and documented as part of the permanent design file.

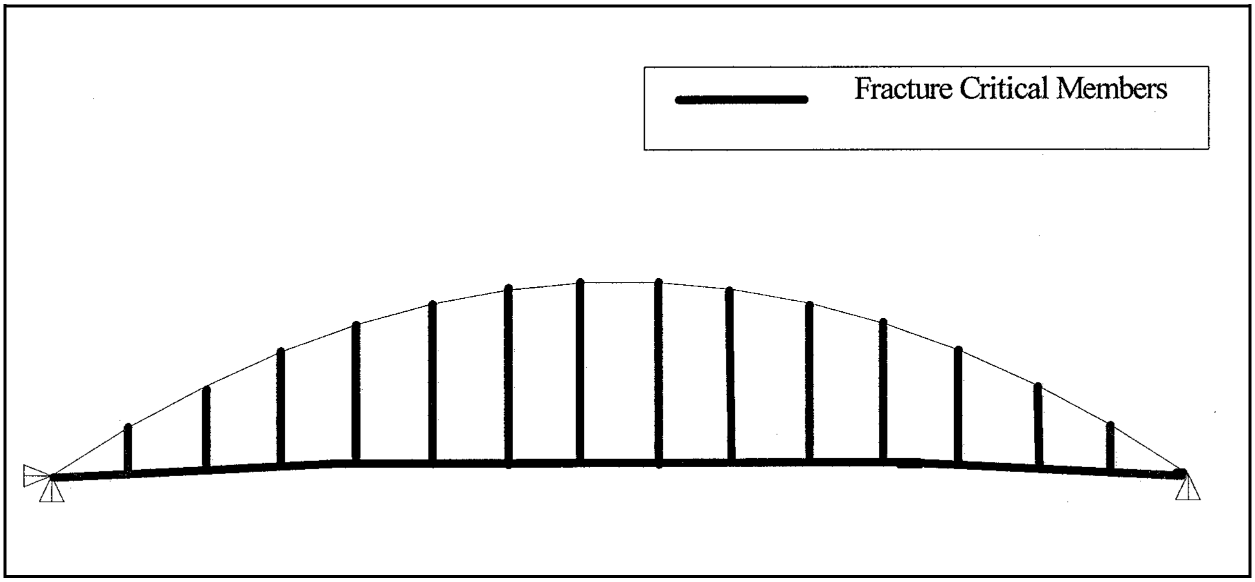

Figure 2-10. St. George's Highway Bridge (FCM in the tied arch span)